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Agent-based Systems Key Enabler for the Army's Future Force

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ABSRACT –*The objective of this paper is to identify and discuss several potential application areas for intelligent agent technology that will enable the US Army to rapidly transform itself from its current military organization and operational capabilities to that of a future, more modern force structure. The thrust of the US Army's transformation concept is to evolve to a lighter, leaner, faster, more highly mobile and agile, command-centric, combined arms force structure that lives in a network-centric world and leverages state of the art information technologies to interpret and understand the evolving battlefield situation and take decisive action before his adversary. In this paper, we will discuss how the implementation of the military decision making process is changing under the Army's transitioning to its future force structure and how and where the application of agent-based systems will be the essential enabler.*

1. INTRODUCTION

The Army's future force structure is envisioned to be a totally integrated force enabling the Commander to deploy and control both weapon and sensor systems that are a mixture of both manned and unmanned, autonomous systems. While these capabilities provide the future commanders tremendous potential and flexibility for adapting and tailoring the actions of their forces to meet the dynamics of a rapidly changing military environment, they must execute these missions with significantly reduced and streamlined force structures. To meet these future challenges, commanders will need to rely on the use of agent-based information collection/analysis processing capabilities and asset management software systems to control the deployment of their military systems in shaping the battle space. In this paper, we will discuss how the implementation of the military decision making process is changing under this transition to the future and how and where the application of agent-based systems will become the essential enablers.

2. ASSUMPTIONS AND TENETS

This paper is concerned with identifying and describing how intelligent agent-based software systems can be used to support the development of new, revolutionary operational capabilities needed to support the US Army in the future. To keep the scope of this paper within reasonable limits, we will focus this discussion to key generic capabilities pertinent to the support of an abstract military action force at the Battalion and below level. The application examples presented are intended to represent extensible models that developers can adapt in defining and implementing agent-based solutions for other echelons and functional areas. A key tenant for the Army's future force concepts is that in an "Information World", US Army commanders will have unlimited access and connectivity to communication networks, bandwidth, and information. Indeed, DOD has undertaken a major initiative to implement and have in place by 2010 a Global Information Grid that will provide Army, Navy, and Air Force commanders plus DOD support agencies with real-time, seamless connectivity across the spectrum, and access to all the information they need to support the execution of their missions and conduct dynamic collaboration with their peers.

Based on this premise, the Army is moving ahead with the development of future, highly mobile and agile, integrated, force structures comprised of both manned and unmanned, combined arms weapons and sensor systems. These action forces specifically designed for rapid deployment operations supporting the full spectrum of warfare. For this paper we do not need to know the detailed make up of these emerging force structures. It is only important to understand that future commanders will have significantly reduced support staffs to direct, allocate and manage the new emerging combat assets. Additionally, commanders executing these functions will be dealing with significantly more diverse and complex environment than those experienced by their predecessors. The dynamics of the future battlefield with its emphasis on high levels of maneuver mobility will require these decision functions to be preformed in a significantly reduced decision timelines.

3. REPRESENTATIVE HYPOTHETICAL TRANSFORMATION FORCE

In the next few paragraphs we will, by example, describe how intelligent agent-based software systems can be used to develop and provide critical C2 functionality and capabilities important to meeting the challenges faced by

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future commanders. To keep this discussion focused on a meaningful application scope, it is necessary to synthesize a representative abstract military force and consider how it operates in an appropriate scenario and problem space. As depicted in Figure 1, let us define a hypothetical action force that consists of "n" different types of action entities. These action entities represent typical types of military entities with different functional capabilities and characteristics, i.e. - (a) Mobile Gun Vehicle, (b) Mobile Rocket Vehicle, (c) a Mobile Missile Vehicle and (d) a Remote Aerial Sensor system. In realty, a future commander will probably have a more diverse and richer mix of action entity types at his disposal. However, for this discussion, the postulated action force will have sufficient complexity to represent the problem space.

Let us assume that this hypothetical action force Commander has a mix of 18 ea Mobile Gun Vehicles, 8 ea Mobile Rocket Vehicles, 2 ea Mobile Missile Vehicles and 2ea Remote Aerial Sensors at his disposal to support a given military operation. Two of the Mobile Gun Vehicles are also serving as mobile Command and Control (C2) and vehicles.

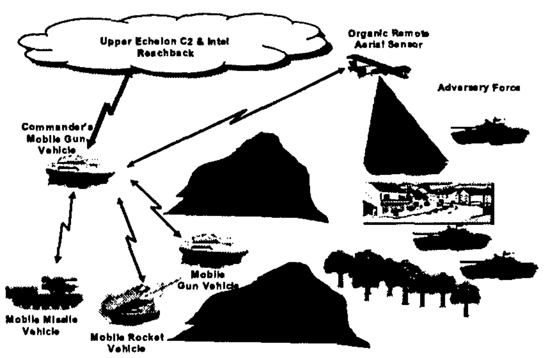

Figure 1 – Hypothetical Unit of Action Force

Note, this is only a hypothetical, illustrative force and does not represent any real military unit. In order to develop an agent model of how this hypothetical action force operates, we need to give its component action entities some conceptual operational capabilities and behavior characteristics. Therefore assume that Mobile Gun Vehicles have an effective, line of site, kill range of Δ_G km. Also, these Mobile Gun Vehicles can fire "on-the-move" and dynamically redirect fires anywhere around 360-degree field of view. Similarly, assume that the Mobile Rocket Vehicle's rockets have an effective non-line of site range which is nominally 3 times the max range of the mobile gun. Also assume that Mobile Rocket Vehicle fires can be used both to generate fire effects and support forward observer and precision strike guided target engagements. Next assume that the Mobile Missile Vehicle's missiles have maximum effective range which is approximately 3 times the max of the rocket. Also assume that launched missiles have the ability to loiter in an airborne orbit for some time, and can autonomously engage pre-programmed, high priority targets. They can also be redirected while in the air to support sensor guided, precision strike engagements. Finally, assume that the Remote Aerial Sensors normally fly up to altitudes of Δ_A meters, can remain on in orbit for Δ_H hours, and have a maximum remote control range from sensor to their base station of which is approximately equal to the max range of a rocket. Additionally, these Remote Aerial Sensors can perform (a) general 360-degree electronic target surveillance activities with detection ranges up to Δ_D km (where $\Delta_D \sim$ max Δ_R); (b) general, line of site optical imaging range is Δ_{OI} km with a Field of View (FOV) of less that 10° that can be steered over a quadrant relative to platform heading bore site, and (c) support precision target tracking and designation operations with an Δ_{PT} km where max Δ_{PT} is approximately ½ the max range the gun, Δ_G. The FOV of the precision strike sensor is an order of magnitude less than that of the optical imaging sensor FOV and also has a narrower sector scan relative platform heading bore site. While each Remote Aerial Sensor is capable of performing all three of these described functions, only one function can be performed in a given period of time. During the course of a mission these supporting sensor functions are only available on a time-share basis. Finally, all of the three ground action entity vehicles can travel across terrain at a max speed v_G km/hr which is speed is twice as fast as that of adversarial ground units. The Remote Aerial Sensor can travel at a max speed of v_A which is approximately 5 times that of the ground vehicles. Again it must be emphasized, that none of the characteristics present here for these envisioned action entity platforms represent anything real. They are only meant to illustrate the kinds of complexity existing in the problem space of discussion. Real world military systems require a Commander to consider and trade-off many more combat systems performance and constraint factors before deploying them than identified in this paper.

4. SITUATION AWARENESS DECISION MAKING

Figure 2 illustrates a typical Situation Awareness (SA) picture that a commander might be presented. What is important to know, is that commanders view this situation picture in terms of their "Area of Operation" (AO), which they break down into several different regions or zones. Specifically, there is a direct "Zone of Influence" where he needs to engage his opponent decisively to assure his survivability and mission success. If an opponent enters into his zone of influence, the commander must decide when, how, and with what assets to engage his opponent forces. Note also that his opponent, the Red Force, will probably be entering the commander's zone of influence with several different, multiple types of action cells or units of his own. Therefore the commander will have to dynamically and appropriately array his tactical force against those of his opponent. The action force Commander does not know precisely where and when his opponent will enter his AO and zone of influence. This opponent, adversarial force may also out number US forces, and be considered a heavy force. However, US action forces are expected to have more and longer range lethality and a higher degree of mobility and agility than that of their opponents.

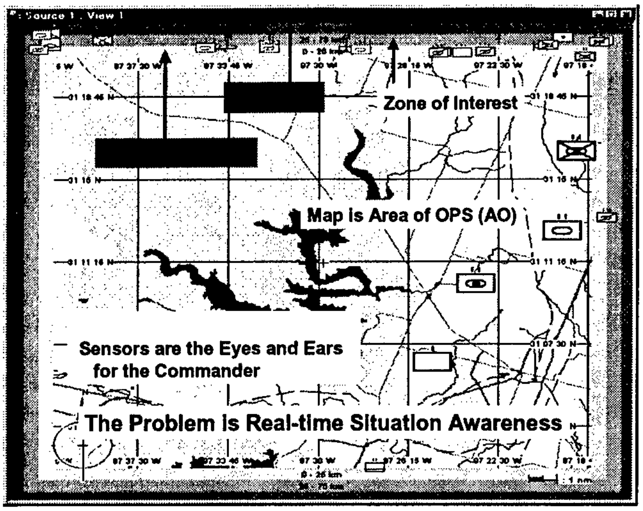

Figure 2 - Typical Situation Awareness (SA) Display

Through the Global Information Grid action force commanders can reach back to tactical intelligence (Intel) for information telling them about what is happening and what to expect in their respective "Zone of Interest" and "Zone of Intel". This reach back capability to data collected via national or higher echelon tactical surveillance assets also provides commanders some information on enemy activity within their "Zone of Influence". However, in the highly mobile environment envisioned for this discussion, US commanders will need to use their organic sensor systems to support the conduct of real-time enemy engagements.

Figure 3 illustrates the information correlation and reconciliation problem US action force commanders are confronted with. The problem space illustrated by Figure 3 is the first area where the application of intelligent agent technology can have a profound influence on improving the C2 decision-making process. As an adversarial force

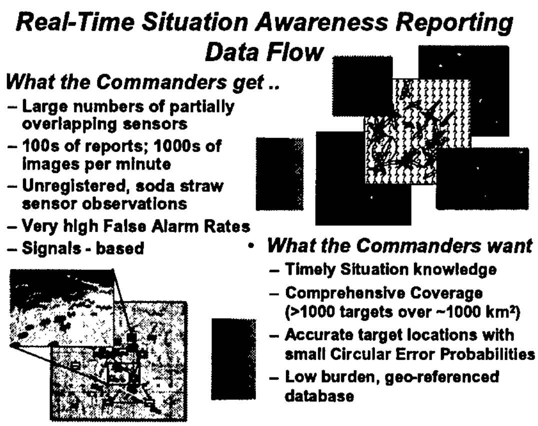

Figure 3 - SA Information Correlation Problem

moves from the US Commander's "Zone of Interest" to his "Zone of Influence" the Commander will most likely deploy his organic Remote Aerial Sensor to get a better look at what is coming towards him. Now he is confronted with how to correlate and reconcile corroborating and conflicting information obtained from both organic and reach back derived sensor reports.

We are not talking fusion here; the commander does not have the time or a support staff to do information fusion processing. The information is what it is, and he has to make sense of it. Mostly the commander wants to know for example, what is it, where is it really, how big and lethal is it, is it really an enemy, how many of them are there really, and how fast are they moving and how much time I have to decisively engage them. Additionally, he also needs to know where his forces and other associated friendly units are currently. All of this information is associated with some notional execution plan for the operation and assumptions on what the adversary is most like to do.

Additionally, even if we can reconcile these reports and keep all this SA information current, under the dynamics of a highly mobile engagement, it would be difficult for the commander to keep up with the changing battlefield picture just by viewing it on a screen. If we properly apply intelligent agent technology to assist in the information processing, management and interpretation of SA data in this problem space, the current enterprise information collection and repository database systems used for development and display of SA can be converted into an active commander's decision support and situation interpretation capability that also has triggers to alert him of critical decision making events needing his attention.

5. AGENTS FOR INTERPRETING OF SA

To implement such intelligent agent-based information correlation and SA interpretation systems, we need to change the paradigm and process we currently use to build the SA picture. If one assumes that the action force Commander is executing his mission as part of an overall operational plan (OPLAN), then there is some vision and description of the tactical entities, both friendly and adversary that are expected to play in the planned operation. In the Modeling and Simulation (M&S) world, agents have been extensively used for emulating the performance of military entities in the execution of a simulated military operation. If we view the evolving SA as a series of snapshots of a simulated military operation, we could use M&S systems to model the execution of a real operation. Additionally, let us view the real SA reporting data coming into the command cell as a source of state information that can be used to correct the state representation of this M&S simulated OPLAN execution to align with reality. Under this paradigm, we open the possibility for developing some radically different kinds automated decision support capabilities for tactical commanders. To implement such an intelligent agent-based interpretive SA system requires accepting some underlying assumptions. First assume that we have a reasonably sufficient library of intelligent agent simulation entities that can emulate all of the movement behaviors of both the tactical friendly and adversary actions entities that would be represented in the SA picture as illustrated in Figure 2. As we observe the movement of these action entities over a period of time, we can establish tracking filters that will enable us to improve both the position accuracy and type identification estimation of these entities as they move from SA "Intel Zone", through "Zone of Interest", into the Commander's "Zone of Influence". The goal is to achieve the highest level of entity position accuracy, type and capability identification once this action entity enters into the "Zone of Influence". With such information the Commander can engage this potential target entity in the most effective and efficient manner achievable.

In simulation space, the agent-based action entity emulators are effectively attempting to simulate the execution of the commander's OPLAN, as he perceived for his action entities and his adversaries on the battlefield. Now as the command cell receives real-world friendly and adversary detection/activity/position reports, we can use them to update the accuracy of the simulated OPLAN SA state information. This problem is not as simple as it may appear at first glance. First of all, in a highly mobile, "on-the-move", military environment, all the information that an upper level commander and staff receive to develop SA, is in reality, old information. How old is dependent on where the Commander sits and views the battle relative where the action is. A soldier looking at potential targets through a rangefinder, or radar operators scanning targets have indeed a near instantaneous view of the target. As long as there is a direct, peer-to peer, closed loop communication channel between this sensor system and the weapon used to engage the target, the information flow between the sensor and the engaging weapon is real-time and of sufficient quality to support the target engagement process. However, if we step back to the Commander one echelon higher, the quality and timeliness of the information he gets degrades significantly from that of the sensor to shooter closed loop situation. A quick analysis and modeling of the information flow process will help explain why this is so.

After sensor system first detects a target, there is a finite processing time that it takes for the sensor system to produce a target report providing essential information such as: - target ID, Type/Classification, location, range and azimuth relative to some reference; direction and speed of travel, etc. These sensor reports are the products sent to and processed by upper echelon C2 information collection nodes to generate the SA picture. This sensor report processing time "α" can vary anywhere from milliseconds, to seconds, and sometimes minutes based on the sensor technologies used, physics of the data collection process, terrain geometry, relative speed of target movement and the information quality requirements needed. Lowering data quality thresholds allows more target reports to be pumped out faster, but adds extra processing burdens on both the communication networks and SA processing nodes. Also, if the sensor can simultaneously monitor multiple targets like general surveillance systems, specific target report updates will only be generated at some finite update rate of "N" per second, which additionally impacts the timeliness and quality of the target report information sent to the upper echelon command node. Therefore, an additional variable delay "β ", the report update delay, further degrades the timeliness and utility of the information passed to higher echelon commanders. Table 1 illustrates for a highly automated sensor data processing system the typical time relationships between α and β for different levels of notional report quality. These times are expressed relative to generic raw target data integration dwell time Δ_{DT} (in the order of fractions of seconds) that is required to assure that target detections fall within acceptable probability of detection and false alarm tolerances. Δ_{DT} is variable from one particular sensor/data collection system to another. Additionally communication network quality of service delays also impact the timeliness and utility of SA information reports. Also, physical loss of target visibility due to terrain, and vegetation blockage, can result in sporadic target tracking SA update reporting timelines.

Report Quality Level	Level of Processing Automation	Typical Report Processing Time Range "α" in sec	Typical Update Rate Time Range "β" in sec
High	High Automation	(300 to 2400) *Δ_{DT}	(600 to 2400) * Δ_{DT}
Moderate	High Automation	(10 to 300) * Δ_{DT}	(450 to 1200) * Δ_{DT}
Low	High Automation	(5 to10) * Δ_{DT}	(300 to 600) * Δ_{DT}

Table 1- Typical Target Reporting Delays vs. Quality

Clearly, the effect of these time delays on a real-world SA tracking of highly mobile entities is significant. If the Commander wants to engage the target, he needs to precisely know where the target is; otherwise he will be wasting precious ammunition shooting at ghost targets. The envisioned agent-based interpretive SA system therefore needs to not only accurately update the state information of the simulated OPLAN, but also forward project where the targets most likely will be at the current time. To perform this function and the real world SA state reconciliations, requires us to look at all of this information in terms of an abstract view of the battlefield terrain and geometry.

Referring back to Figure 2, the action force Commander's primary need is accurate information is within in his designated "Zone of Influence". For the purpose of this discussion, consider segmenting this "Zone of Influence" into a honeycomb grid of 1 km diameter octagons as represented by Figure 4. The center of octagon is expressed in lat/long coordinates. The octagon faces are labeled clockwise N, NE, E, SE, S, SW, W, NW, respectively. The slope grade and direction of the line from each octagon face to the center of the octagon can be classified as (+) or (-) flat, mild rolling, steep, etc. Likewise, terrain surface and vegetation characteristics of the octagon can also be classified. All Grid routes can be defined by linking Grid Centers. Road Networks and waterways such as rivers, lakes, etc. are indicated as Obstacle overlay objects. Once we have compiled this type information into an abstract knowledge base of the battle space terrain, we have the

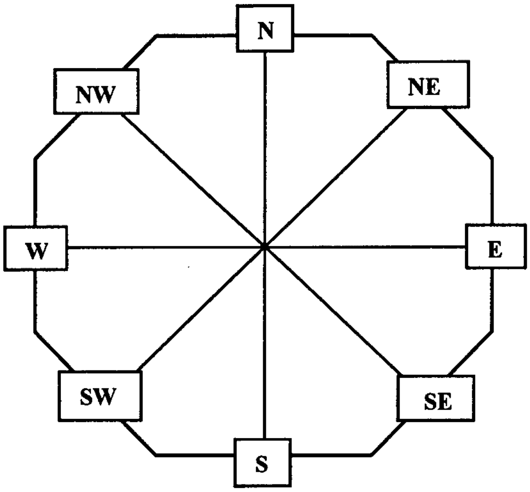

Figure 4 - Battle Space Terrain Abstraction Model

necessary ingredients to implement the envisioned intelligent agent-based interpretive SA decision support system.

At any observation instant the simulated friendly and adversarial entities will be in or near one of these terrain octagons. The real world observation data also references an entity in one of these octagons at any instant of time. Through the use of Bayesian, or other appropriate information cluster analysis processing techniques, we can either associate this real world observation data with one of the currently simulated entities, or decide to introduce a new entity into the simulated entity SA tracking space, initiate/continue tracking it, and alert the commander. For those entities that we can automatically associated the real world observation data, we automatically correct the simulated position state data at the observation time window, and then use the entities autonomous movement behavior to derive projections of where the entity is on the battle space at the current time.

These agent-based entity emulators need and use the information available in abstract terrain knowledge base to determine where, how fast and how far they can transverse the battle space to get to their next position. Additionally, since these agent-based entities are also simulating the execution of the perceived OPLAN, one can insert into the agent-based interpretive SA decision support systems necessary event triggers that let the Commander automatically know what is happening, that is when the adversary is actually entering a pre-designated area, high priority threats are coming into range, the adversary is not doing what was expected, friendly unit are not going arrive at appropriate synchronizing phase lines as planned, etc.

6. AGENTS FOR MANAGEMENT OF THE FORCE

Having set the basis for how intelligent agent-based technology can be applied to support the action force Commander's needs for information processing and interpretation of SA, we will move on to a related problem space. Consider the problem space of efficiently allocating and managing tactical assets in the execution of a mission. Let us focus on the dynamic reassignment problem space where the Commander needs to effectively react to changing events and situations on the mobile battlefield. The hypothetical action force defined for Figure 1 consisted of several highly mobile action entities. Each of these theoretical action entities were described in terms of different capabilities and behavior characteristics. These abstract action entities representations are sufficient to all us to setting up a conceptual model for C2 decision-making that mirrors the processes and dynamics future Commanders will face. In real life these actions entities would have additional functionality, capabilities, behaviors and constraints that must be taken into account and modeled. For instance, these entities probably have different movement, setup, weapons fire, effects, munitions/target engagement service, etc. capabilities. The details of all of these constraints, including logistics support and re-supply will not be considered in this discussion. However, in real life, they are considered in the C2 decision-making process.

The previously discussed interpretive SA, agent-based decision support system used agents to model and track the movement behavior of action entities and project their current location. Now we will discuss another way of using agents to help commanders make better decisions in reacting to changing, unplanned for events. Consider now implementing software agents that model the functional timeline processes of each the action entities described in our theoretical force. These software agents reside on each of these action platforms and maintain the current state information on platform status, resources, etc. They basically know and maintain knowledge on what mission and tasks these action entities are currently assigned and executing, the timelines and process steps needed to service these and the next assigned tasks, know the movement characteristics, fuel consumption and behaviors of the platform in moving from one task location to another, etc. These action entity agents have the needed computational capabilities to analyze and automatically develop action profiles and short term Courses of Action (COA) for the action entity commander in responding to new, immediate action requirements. In this concept, the agents know the real state of action entity and present the entity commander with his options for meeting a new requirement, but do not make the final decision. The action entity Commander makes the decision, and the agents assist in prosecuting the selected COA. Any action entity is part of an action force collective, and like the Commander is able to interact and collaborate with other action entities in developing action plans for servicing new engagement events. In fact, a single action entity may need to collaboratively work with other actions entities to service an action event requirement beyond the capabilities of a single, one on one action entity engagement. While the agent technology development community has demonstrated several different architectures for connecting and supporting agent interaction, the DARPA developed Control of Agent Based Systems (CoABS)[1] middleware infrastructure provides a standardized mechanism for networking agents in a collaborate support environment. CoABS allows multiple agents to operate as a loose federation support by a communication network environment having characteristics similar to what DOD expects to implement for Global Information GRID. More information on the CoABS Grid architecture and capabilities can be obtained the Global Infotek Inc. website at http://www.globalinfotek.com.

So if we conceptually connect our action entity agents via the CoABS Grid network as illustrated in Figure 5, one opens the potential for supporting C2 Decision making from a completely different perspective, a paradigm shift leading to better decisions in a reduced decision cycle. The C2 Decision making architecture depicted in Figure 5 basically represents an agent-based service request environment. The following example will illustrate how the C2 decision-making process would work in the environment depicted in Figure 5. First recall that all of the action entities represented in the figure are also already on the battlefield, moving and executing tasking from a previously developed OPLAN. The action force Commander is alerted by the agent-based interpretive SA decision support system that an adversarial entity is entering his area of influence. Based on this alert he determines that he needs to rapidly engage this adversarial entity. He is not sure of the size, lethality and engagement priority this adversary should have and what friendly assets should be arrayed against him. The Commander uses his command agents to issue an information service request to his action entity agents on the network. He wants one of the Remote Aerial Sensor to take a closer look at the target adversary. The Remote Aerial Sensor agents negotiate between themselves to how they can best service the Commander's new information needs and still perform existing tasking. These agents negotiate the appropriate redistribution of currently scheduled and on-going missions to allow one or both of them to meet the commander's new service request and still successfully complete past assigned actions. These agents' knowledge base includes the details of what it takes to get a Remote Aerial Sensor launched, moved or repositioned to the best observation orbit, on-station loitering timelines, needed mode of operation, etc. necessary to execute this new service request. They initiate preliminary collaboration with all support agents to confirm execution feasibility of service COA options that they determine meet the Commander's service requirement. These agents report back to the Commander and his command agents the execution COA options they have developed; the Commander selects his action preference and the Remote Aerial Sensor agents initiate action to execute the selected COA.

Similarly, the other action entity agents analyze their current action states and determine through a similar negotiation process how they can best meet the Commander's service request while still satisfactorily executing their current mission assignments. Again these agents negotiate amongst themselves for support and redistribution of mission assignments as needed to allow them to reposition for engagement of the adversarial entity. They also continuously interact with the sensor agents for continuously update on adversary location while developing engagement COA options.

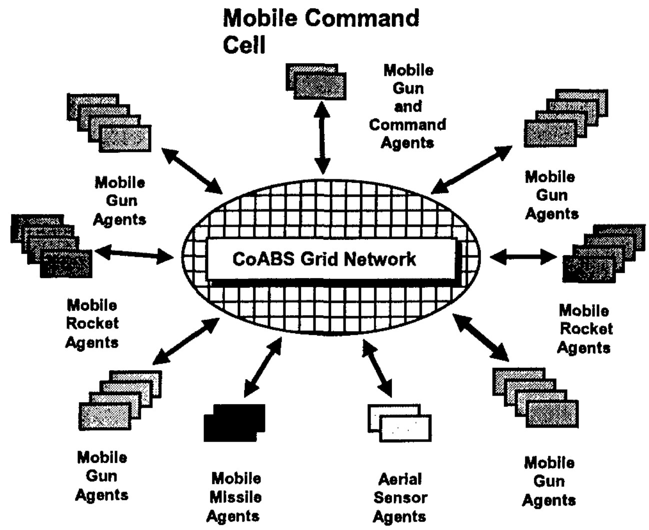

Figure 5 – C2 Agent Service Request Architecture

Once the Commander selects a COA option, these agents facilitate its execution. The selected COA is really a consensus COA in which all action entity agents and entity commanders participated. Each action entity Commander prescreens and recommends to the action force Commander his preferred COA options. In fact, the entity agents are capable of factoring in and refining COA option variations inputted directly by any and all of the commanders in this collaboration process. These networked agents, with their knowledge and rule bases, are still just sophisticated tools supporting rapid feasibility computation and generation of engagement COA. The Commander's vision establishes the "Art of War" and the Commander makes the decisions, not the agent software in this discussion.

7. CONCLUSIONS AND SUMARY

This paper laid the foundation and discussed two major application areas where the use of agent software technology can lead to new ways for implementing C2 decision-making. These agent-based C2 decision support applications would enable future commanders to make better, more informed and decisive decisions in a reduced decision cycle timelines. The conceptual applications and solutions presented represent just the beginning, the future will be dictated by the creativity of the researchers evolving and applying this technology to the needs of the military.

REFERENCES

1. "Control of Agent Based Systems (CoABS) Project Description", Global Infotek Inc. website at http://www.globalinfotek.com .